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The Effect of Simulated Acid Rain on Seedling Emergence and Growth of Eleven Woody Species

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16. ABSTRACT

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Although eight species were affected by simulated acid rain, the direction and magnitude of effects varied with species and with treatment. Seedling emergency was stimulated by at least one acid treatment for four species and inhibited for one species. Top growth was stimulated for at least one acid treatment for four species, while root growth was inhibited for one species. Except for one species, whose emergence rate and top growth were both affected, effects were confined to one measured parameter.

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ADDITIONAL KEY WORDS. Sulfuric acid; northeastern species; northwestern species.

WITHIN THE PAST TWO TO THREE DECADES, the acidity of precipitation has increased (Bolin and others 1971, Braekke 1976, Cogbill and Likens 1974, Gambell and Fisher 1966, Likens and Bormann 1974). By 1972 the precipitation of most areas east of the Mississippi River was more acidic than the value of pH 5.6 resulting from equilibration of rainwater with atmospheric CO_2 at 300 ppm and 25°C.

A large part of the northeast receives precipitation at an average pH of 4.0 or lower. This acidity is largely the result of the loading of atmospheric water with sulfuric and nitric acids derived from sulfur dioxide (SO_2) and oxides of nitrogen (NO_x). The phenomenon occurs regionally, with the impacted areas often hundreds and even thousands of kilometers from the original sources of emission (Bolin and others 1971; several papers in Dochinger and Seliga, eds 1976; Likens and Bormann 1974).

The effects of acidic precipitation on aquatic and terrestrial ecosystems are numerous and complex. These effects involve the elimination of fish populations inhabiting acidified waters and the decline of aquatic invertebrate populations (Braekke 1976; Jensen and Snekvik 1972; several papers in Dochinger and Seliga, eds 1976). The effects of acid rain on soils and vegetation are not as clear. However, in experiments involving simulated acidic rain, effects have included: an increase in leaching of nutrients from plant foliage and soils; an inhibition or

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stimulation of certain plant diseases; foliar injury; influences on the growth of plants; and an inhibition of the nitrogen-fixing activities of legumes (Evans and others 1977; Dochinger and Seliga, eds 1976; Jonsson and Sundberg 1972; Reuss 1975 and 1978; Weber and Lee 1976; Wood and Bormann 1975). Depression of fertilization and sporophyte production by acid precipitation has been observed in ferns (Evans and Bozzone 1977). Conifer germination and seedling establishment were shown to be pH dependent (Braekke 1976), as was the growth of yellow birch and eastern white pine seedlings (Wood and Bormann 1974 and 1975). Results from computer simulation experiments involving the interaction of acid rain and soil indicate that increased anion loading of acid soils results in an immediate increase in the acidity of soil water and an increase in the rate of cation leaching (Johnson and Cole 1977, Reuss 1978).

In 1976, we initiated a multiyear experiment to study the effects of simulated acid rain on nutrient cycling in forests (Lee and Weber 1976). Using the same facility and acid rain treatments, we have examined the effects of simulated acid rain on seedling emergence and growth for various woody species.

Methods and Materials

Seeds of eleven woody species were placed on the surface of a soil mixture containing equal parts Bohannon topsoil, silica sand, and pea gravel. The Bohannon soil, obtained from Siuslaw National Forest, Oregon, is a moderately well drained clay loam, is acidic (pH 5.4), and has a cation exchange capacity of 32 meq/100 g. It is also a very strong sulfate adsorber (Johnson and Cole 1977). The soil mixture was placed in 37 cm × 51 cm cedar flats to an approximate depth of 6 cm. Flats were lined with polyethylene with openings for drainage. After seeds were placed on the soil surface, they were covered with approximately 2.5 cm of mulch obtained by grinding fallen leaves of bigleaf maple (*Acer macrophyllum* Pursh). The flats, soil mixture, and mulch were pasteurized at 75°C for one hour by use of aerated steam before the seeds were introduced. In one group of eight flats, each flat received 130 seeds of sugar maple (*Acer saccharum* Marsh.), 150 seeds of flowering dogwood (*Cornus florida* L.), 200 seeds of red alder (*Alnus rubra* Bong.), 60 seeds of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco), 80 seeds of eastern white pine (*Pinus strobus* L.), and 160 seeds of eastern redcedar (*Juniperus virginiana* L.). In a second group of eight flats, each flat received 125 seeds of staghorn sumac (*Rhus typhina* L.), 220 seeds of American beech (*Fagus grandifolia* Ehrh.), 200 seeds of yellow birch (*Betula alleghaniensis* Britton), and 65 seeds of shagbark hickory (*Carya ovata* (Mill.) K. Koch). In the third group of eight flats, each flat received 1,000 seeds of tulippoplar (*Liriodendron tulipifera* L.).

All flats were distributed among eight nozzle systems with one flat of each group to each system, for a total of three flats per system. All nozzle systems received a stock solution approximating nonacidic rains containing 11 μeq/l Ca^{++}, 12 μeq/l NH_4^+, 5 μeq/l Na^+, 2 μeq/l K^+, 5 μeq/l Mg^{++}, 11 μeq/l SO_4^{--}, 12 μeq/l NO_3^-, and 12 μeq/l Cl^-. These concentrations were based on a 7-year average from Hubbard Brook, New Hampshire (Likens and Borman 1972), after elimination of estimated sulfuric and nitric acid components. One pair of nozzle systems (the controls) received only the stock solution equilibrated with atmospheric CO_2 to approximately pH 5.6. Three pairs each received sufficient H_2SO_4 to lower the pH to 4.0, 3.5, or 3.0. The nozzle systems applied simulated rain to the flats at the rate of 2.5 mm/hr for 3 hours per day, 3 days per week. Shade cloth was positioned over flats during simulated rain events, yielding 73 percent reduction in light intensity. The flats and nozzle systems were located under a transparent roof (90 percent transmittance) open on the ends and sides. Seeds were thus

TABLE 1. The effect of simulated acid rain on the percent of planted seeds producing seedlings visible above mulch.

Species	Seedlings emerging per treatment of —				Species average	Significance level[a]
	pH 3.0	pH 3.5	pH 4.0	pH 5.7		
	Percent				*Percent*	
Douglas-fir	59.2	40.0	50.0	42.5	47.9	0.05
Eastern white pine	96.3	94.4	98.1	80.6	93.6	0.01
Eastern redcedar	71.9	67.5	63.4	54.7	64.4	0.01
Flowering dogwood	39.3	34.3	34.0	37.0	36.2	NS
Staghorn sumac[b]	5.6	9.6	0.8	15.6	4.8	0.05
Red alder	2.5	2.8	2.8	2.0	2.5	NS
Shagbark hickory	43.1	46.2	47.7	56.9	49.0	NS
Yellow birch	18.3	10.5	11.0	4.3	11.1	0.01
Sugar maple	19.6	17.6	15.4	20.4	17.3	NS
American beech	29.8	30.5	34.5	29.8	30.7	NS
Tulip-poplar (June)	1.4	1.5	2.2	2.2	1.8	NS
Tulip-poplar (August)	2.2	1.7	2.8	2.4	2.7	NS

[a] As determined from corrected chi-square.

[b] Significance maintained even if exceptionally low result at pH 4.0 is not used in analysis.

subject to ambient temperature, relative humidity, and light intensity except during simulated rain events. The facility is located on the Schmidt Research Farm of Oregon State University, near Corvallis, Oregon.

Treatment began on January 20, 1977. Beech was harvested on June 7, 1977, and maple on June 8, when canopy competition became imminent. Dogwood, Douglas-fir, eastern white pine, and redcedar were harvested on July 8, 1977. Sumac, hickory, birch, tulip-poplar, and alder were harvested on August 30, 1977, after emergence had apparently ceased. The numbers of harvested seedlings were recorded, and the tops and roots were separated, ovendried, and weighed. Tulip-poplar seedlings were counted on June 12 and harvested on August 30.

Results

Emergence rate was estimated by the percent of seeds producing plants visible above the mulch during the test period. Table 1 gives the emergence rate of each species by treatment. Since the beech seeds in two flats (treatment pH's 3.0 and 4.0) were disturbed by rodents, data for all species (beech, birch, hickory, sumac) in these flats were discarded and only data from the remaining flats were used. Based on tests of corrected chi-square (Snedecor and Cochran 1968), we observed significant treatment effects for five species. Simulated acid rain inhibited germination of staghorn sumac but stimulated germination of eastern white pine, eastern redcedar, and yellow birch, as compared to the controls. Douglas-fir showed a mixed response. While not statistically significant, inhibition of shagbark hickory and tulip-poplar emergence was suggested.

Table 2 gives the average ovendried weight of the top of each species by treatment. Based on *F*-Tests (Snedecor and Cochran 1968), no species had a statistically significant inhibition of top growth by simulated acid rain. However, the progressive decrease in the top weights of yellow birch suggested possible inhibition. Top growth of Douglas-fir and shagbark hickory was stimulated. Sugar maple showed a mixed response in which the lowest pH treatment produced top growth similar to that of the control, while the intermediate treatments stimulated

TABLE 2. The effect of simulated acid rain on the top growth of various species of woody plants.

Species	Average top dry weight per treatment of —				Species average	Significance level[a]
	pH 3.0	pH 3.5	pH 4.0	pH 5.7		
	mg				*mg*	
Douglas-fir	56	46	48	41	48	0.01
Eastern white pine	50	49	49	49	49	NS
Eastern redcedar	23	20	22	20	21	NS
Flowering dogwood	69	66	65	64	66	NS
Staghorn sumac[b]	371	237	—	385	329	NS
Red alder	47	119	109	92	93	NS
Shagbark hickory	335	379	328	260	312	0.10
Yellow birch	58	69	89	197	82	NS
Sugar maple	92	121	120	92	104	0.05
American beech	115	125	111	114	116	NS
Tulip-poplar	48	54	102	54	68	0.01

[a] As determined from *F*-test.
[b] Weight of single plant harvested at pH 4.0 not used in analysis.

growth. The growth of tulip-poplar was much greater at pH 4.0 than at other pH treatments. The remaining species showed very little variation with treatment.

Table 3 gives the average ovendried weight of roots for each species by treatment. Only staghorn sumac was significantly inhibited by simulated acid rain. The growth of roots of other species was not altered.

Discussion

Observation of a nonmonotonic response to acid rain is consistent with studies in which Scotch pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) showed optimal germination and seedling establishment at pH values of 4.2–4.4 (Braekke 1976). This suggests that the net effect might result from competing stimulatory and inhibitory effects. Stimulation of germination might possibly result from scarification of seedcoats. For redcedar, mild acids are sometimes used to stimulate germination (USDA Forest Service 1974). Stimulation of top growth could result if sulfate absorbed by leaves had a fertilizing effect; inhibition could occur if sulfate accumulated to toxic levels or if the acid caused direct injury to the leaves.

The strong sulfate adsorbing property of Bohannon soil implies low sulfate concentrations in the soil solution, even for the most acid treatment (Johnson and Cole 1977). The observed differences in seedling growth were thus probably due to direct effects on the foliage, rather than to the small differences expected in soil solution concentrations of cations and anions (Johnson and Cole 1977, Reuss 1978). Low sulfate concentrations would enhance the possibility of sulfur fertilization by sulfuric acid rain. Brady (1974) suggests that plants growing in sulfur deficient soils may obtain most of their sulfur from atmospheric sulfur, including acid rain.

Stimulation of seedling growth by simulated acid rain at pH values 4.0 or lower was observed by Wood and Bormann (Dochinger and Seliga, eds 1976, p 819–825). Eastern white pine seedlings which received 4.5 cm/wk of simulated acid rain containing sulfuric, nitric, and hydrochloric acid in the ratio 66:24:10 (chemical equivalent basis) grew more rapidly than those receiving a control rain. Their

TABLE 3. Average root weight of seedlings treated with simulated acid rain.

Species	Average root dry weight per treatment of —				Species average	Significance level[a]
	pH 3.0	pH 3.5	pH 4.0	pH 5.7		
	mg				*mg*	
Douglas-fir	18	15	15	13	16	NS
Eastern white pine	19	17	17	19	18	NS
Eastern redcedar	4	3	4	4	4	NS
Flowering dogwood	29	27	30	31	29	NS
Staghorn sumac[b]	151	120	—	171	146	0.01
Red alder	15	24	25	17	20	NS
Shagbark hickory	945	1,058	1,092	914	974	NS
Yellow birch	25	31	29	70	32	NS
Sugar maple	40	62	50	29	45	NS
Tulip-poplar	31	26	32	35	31	NS

[a] As determined from *F*-test.
[b] Root weight of single plant harvested at pH 4.0 not used in analysis.

hypothesis that this was due to NO_3^+ fertilization, rather than to an H^+ effect, is supported by our observation of a null result for eastern white pine seedlings receiving simulated sulfuric acid rain.

Effects on emergence rate and the growth rate apparently were unconnected. Only Douglas-fir had significant changes in both rates, with both generally increasing with higher acid concentrations. The data for shagbark hickory and yellow birch are suggestive of opposite trends in germination and growth, possibly due to differences in seedling competition associated with differences in population density with acid rain treatment. Inhibition of yellow birch seedling growth was observed by Wood and Bormann (1974) for simulated sulfuric acid mist at pH 2.3, but not at pH values of 3.0 or higher.

Of the eleven species tested, eight species were affected by simulated acid rain at pH 4 or lower. This suggests that acid rain, at concentrations typical of the northeastern United States, is strong enough to affect the germination rate or seedling growth rate of a large fraction of forest woody species. For forests growing on sulfur deficient soils foliar sulfur fertilization of some species by sulfuric acid rain is possible. On a sulfate adsorbing soil foliar fertilization might continue for one or two decades, until the adsorbed sulfate approaches the soil's sulfate adsorbing capacity and sulfate concentration increases in the soil solution (Johnson and Cole 1977, Reuss 1978). On any soil, inhibition of seedling growth by acid injury to foliage is possible.

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